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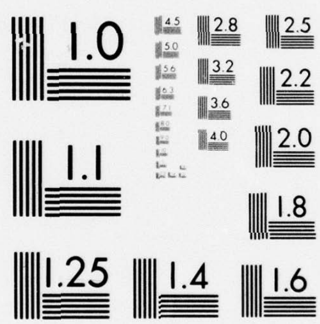

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NWC TP 5952

Experiments With Color Coding on Television

by
Dan W. Wagner
Systems Development Department

JANUARY 1977

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

R. G. Freeman, III, RAdm., USN . . . . Commander
G. L. Hollingsworth . . . . Technical Director

FOREWORD

These experiments with color coding on television were conducted at the Naval Weapons Center, China Lake, California, between February and October 1976. The task is part of a Naval Air Systems Command program on Human Factors Engineering. It is supported by AirTask No. A03A-3400/00813/7F55-525-000 under the direction of CDR Paul Chatelier (AIR-340F).

This report has been reviewed for technical accuracy by R. A. Erickson.

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(U) *Experiments With Color Coding on Television*, by Dan W. Wagner. China Lake, Calif., Naval Weapons Center, January 1977. 18 pp. (NWC TP 5952, publication UNCLASSIFIED.)

(U) Three experiments were conducted to investigate the effectiveness of color coding in a potential cockpit application. The experiments measured the subjects' ability to monitor random malfunction indications, shown in either color-coded, single color, or black-and-white conditions on simulated engine management displays. The subjects were simultaneously engaged in a dynamic target detection task on an adjacent display during the monitoring task. Ambient illumination color and subject experience were additional variables.

(U) The results show that response time on the target detection task was faster when the engine display was color-coded than when it was black-and-white. Time to report malfunctions was slower with red or green monochrome displays than with the other colors. The response time in reporting malfunctions on the black-and-white display was not affected by the choice of color on the adjacent display. Finally, performance on target detection and malfunction reporting was not affected by ambient illumination or the experience of the subjects.

CONTENTS

INTRODUCTION

Aircraft cockpits of the future very likely will contain visual displays capable of conveying the information from the many existing gauges, dials, and discrete indicators onto, perhaps, two, three, or four programmable multifunction displays. This integrated approach to cockpit instrumentation is being pursued by the Navy with its Advanced Integrated Display System (AIDS) (see Figure 1), while the Air Force is working on a similar program called the Digital Avionics Instrumentation System. The Army is developing fiberoptic displays and solid-state electronics to replace conventional helicopter engine dials and gauges.

It is conceivable that this work may eventually lead to a standardized cockpit control and display arrangement common across the military services and even commercial airlines. For example, the right-hand instrument, such as a cathode ray tube (CRT) or liquid crystal display, might present preflight and take-off checklists as well as warning and caution advisories together with suggested corrective actions, thus eliminating most of the warning and advisory lights scattered throughout the cockpits of sophisticated aircraft. The goal of the effort is to increase the efficiency of the pilot and aircraft by eliminating errors of indicator interpretation and reducing the response times for the various contingencies.

FIGURE 1. Advanced Display Concept.

One of many questions to be answered in developing the integrated display concept is, "Should the displays be capable of presenting the information in conventional black-and-white (B&W), a single color (monochrome), several colors, or perhaps some combination of the above?" The state-of-the-art for monochromatic and B&W displays is well advanced—at least, for CRT representations—and would require only moderate developmental effort. Color appears to offer an attractive alternative. Although the technology is less advanced, it provides another dimension—color—to the form and luminance presentations of the other displays. It is to this added dimension of color and its potential uses in aircraft cockpits that the remainder of this report is addressed.

BACKGROUND

Several recent literature reviews have been concerned with the use of color in visual displays.[1,2,3] Color has been studied both as a method of presenting realistic or natural imagery and as a means of coding information. Only a few studies involving natural color representations on displays are reported. Studies using color compared to B&W film tend to show that color reduces response time and errors while increasing the number of target detections.[4,5,6] However, experiments designed to simulate air-to-ground target detection and recognition tasks with color compared to B&W television have failed to show that color consistently improves performance.[7,8,9]

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[1] Naval Weapons Center. *Color Coding—An Annotated Bibliography*, by Dan W. Wagner. China Lake, Calif., NWC, March 1977. (NWC TP 5922, publication UNCLASSIFIED.)

[2] Army Human Engineering Laboratory. *Color Coding—A Review of the Literature*, by Thomas C. Cook. Aberdeen Proving Ground, Md., HEL, November 1974. (Tech Note 9-74, publication UNCLASSIFIED.)

[3] R. E. Christ and W. H. Teichner. *Color Research for Visual Displays*. New Mexico State University, Las Cruces, N.M., July 1973. (JANAIR Report 73073, publication UNCLASSIFIED.)

[4] Army Behavior and Systems Research Laboratory. *Intelligence Information From Total Optical Color Imagery*, by T. E. Jeffrey and F. J. Beck. Arlington, Va., ABSRL, November 1972. (Research Memorandum 72-4, publication UNCLASSIFIED.)

[5] Honeywell, Inc. *Target Recognition Performance With Chromatic and Achromatic Displays*, by J. I. Markoff. Minneapolis, Minn., HI, 1972. (SRM-148, publication UNCLASSIFIED.)

[6] A. H. Tickner and E. C. Poulton. "Watching for People and Actions," *Ergonomics*, Vol. 18 (1975), pp. 35–51.

[7] Naval Weapons Center. *Target Detection With Color Versus Black and White Television*, by Dan W. Wagner. China Lake, Calif., NWC, April 1975. (NWC TP 5731, publication UNCLASSIFIED.)

[8] Martin-Marietta Corporation. *Target Acquisition Studies: (2) Target Acquisition Performance—Color Vs Monochrome TV Displays*, by F. D. Fowler and D. B. Jones. Baltimore, Md., January 1972. (OR 11, p. 768, publication UNCLASSIFIED.)

[9] Naval Weapons Center. *Target Acquisition With Color Vs. Black and White Television*, by Dan W. Wagner. China Lake, Calif., NWC, October 1975. (NWC TP 5800, publication UNCLASSIFIED.)

The literature on color-coding displays is considerably more abundant. It generally indicates that, as a coding method, color is helpful for search-and-locate tasks, but numbers are more effective for identification tasks. For example, Christner and Ray[10] investigated colors, numbers, and shape-target codes in combination with a variety of backgrounds for tasks involving locating, counting, identifying, comparing, and verifying. They found that color provided the best performance for locate-and-count tasks, while numbers were best for identification tasks, and no significant difference was found among the three coding methods for comparison and verification tasks. Hitt[11] studied these tasks also, but included the two additional coding methods of letters and configurations (i.e., the placement of small squares within larger squares). He found that numbers and colors were the superior coding methods, with no significant difference between the two except for the symbol identification task, for which numbers were better.

If color can be used to effectively locate or call attention to objects on a display, as the literature suggests, then what display colors will provide the best performance? A number of studies have investigated the question, with the result being that from 4 to 60 colors can be encoded, depending upon training and practice time, performance measure, type of display, and the task.[12,13,14,15,16] Usually, however, four to six colors are considered practical with red, green, yellow, blue, and white frequently mentioned as the most likely candidates.[17,18,19,20]

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10 C. A. Christner and H. W. Ray. "An Evaluation of the Effect of Selected Combinations of Target and Background Coding on Map-Reading Performance," *Exp. V, Hum. Factors*, Vol. 3 (1961), pp. 131–146.

11 W. D. Hitt. "An Evaluation of Five Different Abstract Coding Methods," *Exp. IV, Hum. Factors*, Vol. 3 (1961), pp. 120–130.

12 Wright Air Development Division. *Absolute Identification of Color for Targets Presented Against White and Colored Backgrounds*, by H. P. Bishop and M. N. Crook. Wright-Patterson Air Force Base, Ohio, WADD, March 1961. (Techincal Report 60-611, publication UNCLASSIFIED.)

13 A. Chapanis and R. M. Halsey. "Absolute Judgments of Spectrum Colors," *J. Psych.*, Vol. 41 (1956), pp. 99–103.

14 Wright Air Development Center. *The Use of Color in Coding Displays*, by D. W. Conover and J. Kraft. Wright-Patterson Air Force Base, Ohio, WADC, 1958. (WADC TR-55-471, publication UNCLASSIFIED.)

15 Bunker-Ramo Corporation. *Guide to Human Engineering Design for Visual Displays*, by D. Meister and D. W. Sullivan. Canoga Park, Calif., BRC, August 1969. (AD 693 237, publication UNCLASSIFIED.)

16 S. L. Smith and D. W. Thomas. "Color Versus Shape Coding in Information Displays," *J. Appl. Psych.*, Vol 48 (1964), pp. 137–146.

17 Federal Aviation Administration, Department of Transportation. *Color Display Evaluation for Air Traffic Control*, by D. W. Connolly, G. Spanier, and F. Champion. Washington, D.C., FAA, May 1975. (Report No. FAA-RD-75-39, publication UNCLASSIFIED.)

18 National Aeronautics and Space Administration. *Response Time to Colored Stimuli in the Full Visual Field*, by R. F. Haines, L. Markham Dawson, Terye Galvan, and Lorrie M. Reid. Washington, D.C., NASA, 1974. (NASA TN D-7927, publication UNCLASSIFIED.)

19 Air Force Systems Command, Rome Air Development Center, Research and Technology Division. *Color Specification for Additive Color Group Displays*, by E. F. Rizy. Griffiss Air Force Base, N.Y., RADC, August 1965. (RADC-TR-65-278, AD 621 068, publication UNCLASSIFIED.)

20 R. Tyte, J. Wharf, and B. Ellis. "Visual Response Times in High Ambient Illumination," *Society for Information Display Digest*, 1975, pp. 98–99.

A further consideration, if color displays are to be used in cockpits, is the color of the illumination. Newer aircraft have used red or white lighting for cockpit illumination during night operations. Red lighting has been used since WW II, since it was known that night (scotopic) vision was better maintained by red light than typical white light. While this fact is well established, the operational significance of it is questionable, because the values were established at or near threshold levels that have little bearing on applied situations. Johnson and Poston[21] recently studied the issue in relation to helicopter pilot visual acuity and peripheral vision performance under red or white illumination. They found that cockpit lighting color was not a significant factor for legibility levels or peripheral vision performance. The interest for the present studies is to determine whether either color affects performance with color displays.

One other variable of interest for studies involving basic airborne target acquisition and monitoring tasks is subject experience. Pilots or other aircrew members are the preferred subjects for these studies, since they are the eventual user population. However, since most studies are parametric and do not require the sophisticated level of training achieved by pilots, and since relatively few pilots are available in comparison with the engineers and other professionals accessible to the groups usually doing these investigations, it would be worthwhile to determine how well several of these groups compare with the pilot group.

OVERVIEW

Three laboratory experiments were designed to investigate the effectiveness of color coding in a potential cockpit application. Experiment I measured the subjects' ability to monitor random malfunction indications on one simulated engine management display while engaged in a target detection task on an adjacent display. Response time and error scores were used to compare performance between color-coded and B&W presentations of 10 engine malfunctions. Experiment II was conducted to determine whether fewer malfunctions per-unit-of-time would increase the relative effectiveness of color coding. The second experiment was similar to the first except that only 3, instead of 10, malfunctions were presented over the same time period.

The relative effectiveness of a B&W, single-color, or two-color coded display was investigated in Experiment III. A second engine management display, shown in black and white, was added to the equipment used in the first and second experiments. This display provided the means of both increasing the monitoring task workload and evaluating the simultaneous use of color and B&W displays. Additionally, the display conditions were seen under red or white illumination to determine if display color interacted with ambient illumination color.

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21 Army Human Engineering Laboratory. *A Comparison of Red and White Cockpit Lighting Under Quasi-Operational Conditions*, by Neil A. Johnson and Alan M. Poston. Aberdeen, Md., HEL, January 1976. (TM 6-76, publication UNCLASSIFIED.)

METHODOLOGY

APPARATUS

The equipment used for these experiments is described below. Figure 2 provides a sketch of the apparatus as arranged for the experiment.

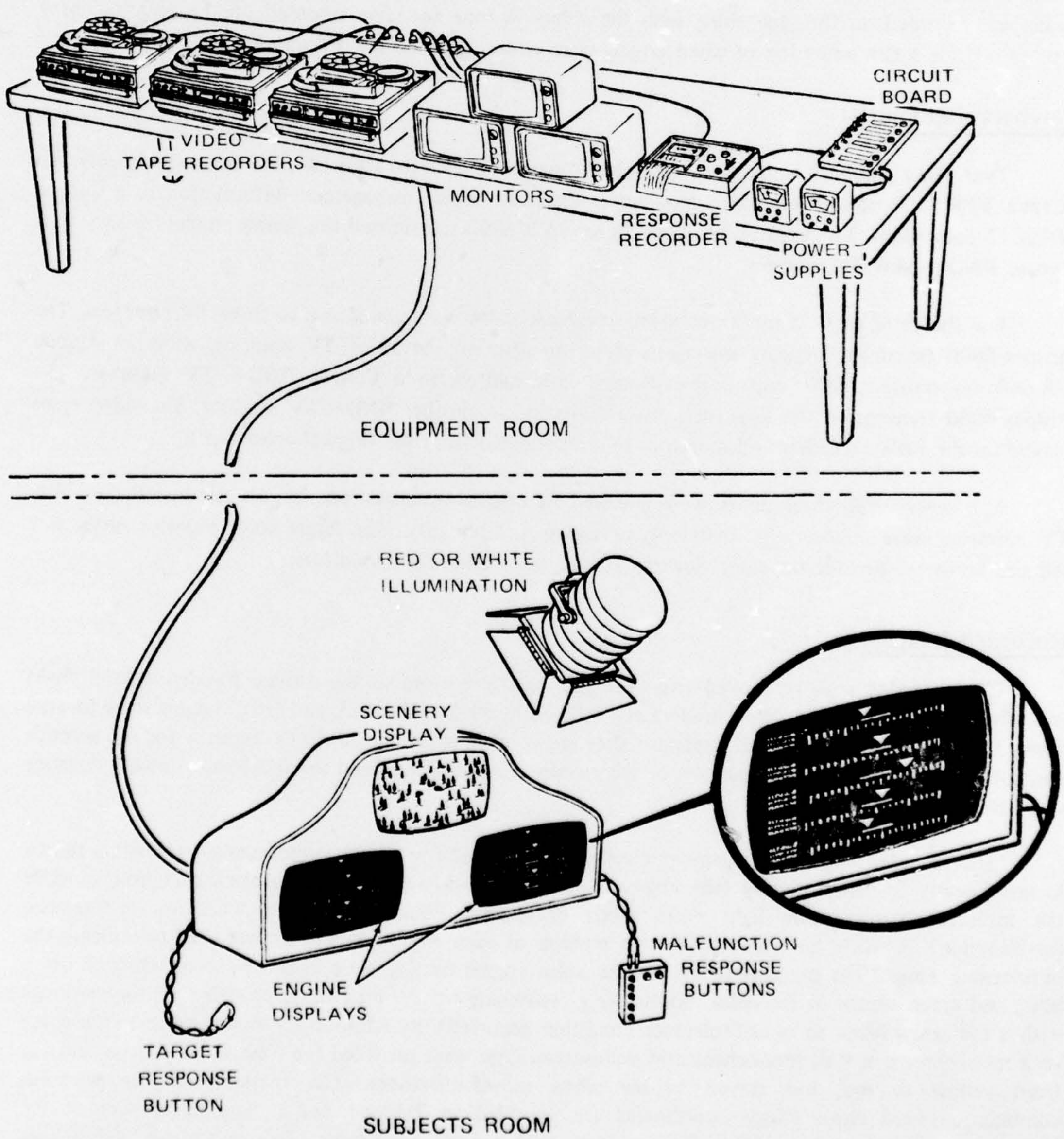

FIGURE 2. Sketch of Experimental Apparatus.

Recording Equipment

An Ampex 5800 color/B&W video tape recorder and a Cohu 1230D color television camera were used to record terrain model scenery containing scale model targets and engine management displays. Full descriptions of the terrain model, targets, and television camera are contained elsewhere.[9]

Electrical contacts were attached to the back of the engine display in such a manner that, when a malfunction occurred, a circuit would close, initiating a 1600-Hz tone from an audio generator. This audio was recorded on the tape along with the video. A tone was also recorded on the target scenery tape to provide a determination of when targets were within view on the TV monitor.

Playback Equipment

Two video playback units were connected to two TV monitors for the first two experiments. An Ampex VPR 5800 color/B&W video recorder transmitted engine management information to a Conrac 5022C12 color/B&W TV monitor, while an Ampex VR 6000 transmitted the terrain model imagery to a Conrac RND-9 B&W TV monitor.

For the third experiment, three video playback units were connected to three TV monitors. The Ampex 5800 transmitted engine management information to the color TV monitor, while an Ampex VR 660 transmitted B&W engine management information to a Conrac RND-9 TV monitor. The Ampex 6000 transmitted the target-scenery information to another RND-9 TV monitor. The video tapes played on the B&W recorders and monitors were duplicated from the original color tapes.

The recorder/playback units were adjusted to original specifications by Ampex technicians. The TV monitors were adjusted for matching geometry and linearity. The larger color monitor raster was reduced in size to provide the same viewing area as the smaller B&W monitors.

Recorded Imagery

The recorded scenery moved from the top to the bottom of the display simulating level flight over the terrain which resembled moderately foliated foothills. The tank and truck targets were located along the test track at irregular intervals. They were in view on the subject's monitor for 6.6 seconds and subtended an angle of 20 minutes of arc to him, as calculated from the maximum viewing distance of 30 inches (762 mm).

The recorded engine management display consisted of five engine-performance parameters shown in one linearly formated display (see Figure 2). The markings were white on a black background, while the indicator arrows were light green when in-tolerance, changing to red when out-of-tolerance (malfunction). A white line located under a portion of each engine parameter was used to indicate the in-tolerance range. The marking colors on the color engine display were varied by controlling the red, blue, and green beams of the color monitor (e.g., switching off the blue beam provided yellow markings with a red arrow when an out-of-tolerance condition occurred). By additionally switching from the color to a monochrome signal, monochromatic yellow markings were provided (i.e., the arrow did not change from yellow to red, but stayed yellow when out-of-tolerance). The marking and arrow color combinations and chromaticity coordinates are provided in Tables 1 and 2. The luminances of the markings were adjusted to 5 ftL (17.1 cd/m^2) (± 1) for all conditions. The underlines and arrows subtended visual angles, respectively, of 4.5 x 35.7 and 11.2 x 15.7 minutes of arc at the maximum viewing distance.

TABLE 1. Engine Display Colors.

Experiment	Markings	Arrows	
		In-tolerance	Out-of-tolerance
I and II	White	White	White
	White	Green	Red
III	Red	Red	Red
	Green	Green	Green
	Blue	Blue	Blue
	Yellow	Yellow	Yellow
	White	White	White
	White	Green	Red
	Yellow	Yellow	Red

TABLE 2. Engine Display Color Specifications.

Color	Chromaticity		Wavelength, nm	Saturation, %
	x	y		
Red	0.656	0.322	630	94
Green	0.323	0.594	550	77
Blue	0.146	0.045	450	97
Yellow	0.434	0.505	572	82
White	0.318	0.290	--	--

Response Buttons

When a subject saw a target, he pushed a hand-held response button. When he saw a malfunction indicated on one of the engine management displays, he first pushed one of two buttons to indicate whether the malfunction was occurring on the right or left display (these two buttons were not used in the initial two studies) and then pushed one of five buttons to indicate which one of five parameters was out of tolerance. These buttons were mounted on a panel in front of the displays. All buttons were wired to a Honeywell 906C 12-Channel Visicorder. The printout from this recorder provided all the required response time and accuracy data for analysis.

Subject Area Lighting

The subjects' monitors were viewed under conditions of red and white illumination for the third experiment. The light incident on the color monitor was measured with a Techtronix J16-6503 illuminance probe. The lighting for the experiment was as follows:

Red	0.4 ftc (4.3 lux)	110V G.E. 50W, 115V
White	0.4 ftc (4.3 lux)	61V W.H. 15W, 120V

General Equipment

Additional equipment used to calibrate and monitor the experimental apparatus included: Gamma Scientific IC 2000K telephotometer to adjust the luminance and measure the chromaticity o the subjects' monitors; a Hellige IRT Mark 3 color comparator to color-balance the color display a 6500K; Visual Information Institute 216 test pattern and 306 synchronization generators to compar and adjust the linearity and geometry of the subjects' monitors; and a circuit designed and built at NW(to convert the audio signals to electronic signals for display on the Visicorder.

EXPERIMENTAL DESIGN

Three studies were designed to compare color-coded to non-color-coded information dynamicall displayed on TV. The first experiment used a 2 x 2 factorial design to investigate color-coded versu B&W displays and experienced subjects compared to naive subjects. For this experiment, an engin display monitoring task contained 10 malfunctions presented over a 22-minute period. Color-code versus B&W displays were evaluated with a single factor design for the second experiment in which onl 3 malfunctions were presented over a 22-minute period.

For the third study, seven display-color conditions, four experience levels, and two colors o illumination were investigated with a 7 x 4 x 2 repeated measures design. Illumination, the repeate factor, was counterbalanced across all subjects. Each display condition was seen by one of seven groups The groups were composed of one subject from each of the four experience levels. In this experiment 13 malfunctions and 33 targets were displayed over each of two 22-minute test periods. The design fo this study is shown in Figure 3.

		Markings						
	Light	Blk/white	Red/white	Red/yellow	Red	Green	Blue	Yellow
Subjects	Red	S_1	S_5	S_9	S_{13}	S_{17}	S_{21}	S_{25}
		S_2	S_6	S_{10}	S_{14}	S_{18}	S_{22}	S_{26}
		S_3	S_7	S_{11}	S_{15}	S_{19}	S_{23}	S_{27}
		S_4	S_8	S_{12}	S_{16}	S_{20}	S_{24}	S_{28}
	White	S_1	S_5	S_9	S_{13}	S_{17}	S_{21}	S_{25}
		S_2	S_6	S_{10}	S_{14}	S_{18}	S_{22}	S_{26}
		S_3	S_7	S_{11}	S_{15}	S_{19}	S_{23}	S_{27}
		S_4	S_8	S_{12}	S_{16}	S_{20}	S_{24}	S_{28}

FIGURE 3. Experimental Design.

SUBJECTS

All of the subjects (Ss) for these studies were Naval Weapons Center personnel between the ages of 22 and 43. The first experiment used 12 civilians in professional occupations who were divided into two groups of naive and experienced Ss based on their prior participation in target acquisition studies. Six civilian professionals of varying experience levels served as Ss in the second experiment. In the third experiment, 28 Ss were assigned to serve in one of four groups: (1) civilian professionals experienced in target acquisition studies (termed as "Test-Wise" subjects); (2) civilian professionals without experience in target acquisition (termed "Naive Civilian"); (3) military pilot and bombardier/navigator officers experienced in target acquisition (termed "Pilots-B/Ns"); and (4) military enlisted men inexperienced in target acquisition (termed "Naive Military"). All Ss were tested on the Bausch and Lomb Armed Forces Vision Tester and had 20/20 or better visual acuity. Additionally, those Ss who participated in any of the conditions involving color had normal color vision as determined with the Dvorine Pseudo-Isochromatic Plates.

PROCEDURE

Each S was shown the experimental apparatus and then seated at a viewing distance of 30 inches (762 mm) from the displays. He was allowed to lean forward, if he wished, but was not allowed to move back beyond the stated viewing distance. Recorded Instructions (see Appendix A) then described the required task and explained the procedure. Next followed 4 minutes of practice involving only the target video and target response button. If the S had difficulty in detecting targets, the video tape was replayed. Then 4 minutes with just the engine management display was practiced, followed by 4 minutes of practice using all displays and response buttons. The experiment was begun when a S could perform the last 2 minutes of practice without error. The experiment proceeded with the S viewing one of the prescribed conditions. When the S had completed this portion of the experiment, the video tapes were rewound in preparation for the next condition. Each portion of the experiment required 22 minutes to complete plus a 5-minute break while the tapes were being rewound. The total time required of a S was typically 70 minutes.

ANALYSIS

Both target detection and malfunction detection times were recorded. Detection time was defined as the interval between the onset of a malfunction or the appearance of a target and the subject's response. Misses were scored as 8 seconds and 12 seconds, respectively, for targets and malfunctions. Errors of omission and commission were also recorded and may be found in Appendix B. Analysis of variance was used to analyze the response time data, while levels within a significant factor were evaluated with Newman-Keuls comparison tests. The t statistic was used to analyze the second experiment, as well as to compare the results between the first and second experiments.[22] And, finally, relative scores were calculated from the response time data. This was done to provide a performance baseline with B&W displays as a standard of comparison for performance with color and color-coded displays. Percent performance change was calculated from the formula

[22] B. J. Winer. *Statistical Principles in Experimental Design*, 2d ed. San Francisco, McGraw-Hill, 1971.

$$\text{Change } (\%) = \frac{R_B - R_C}{R_B} \times 100$$

where R_B is the B&W mean response time and R_C is the response time to a display under the specified color condition.

RESULTS AND DISCUSSION

Three experiments were conducted in which Ss were required to detect targets on one TV display while monitoring one or two engine management TV displays under various display-color conditions. The results of these experiments generally indicate that there is a slight advantage to color-coded displays over B&W displays (Figures 4 and 5). It was found that an engine display in certain colors (e.g., yellow) can be used with B&W displays without degrading performance and that the color of the low-level ambient illumination (red or white) has no effect on performance, regardless of display color.

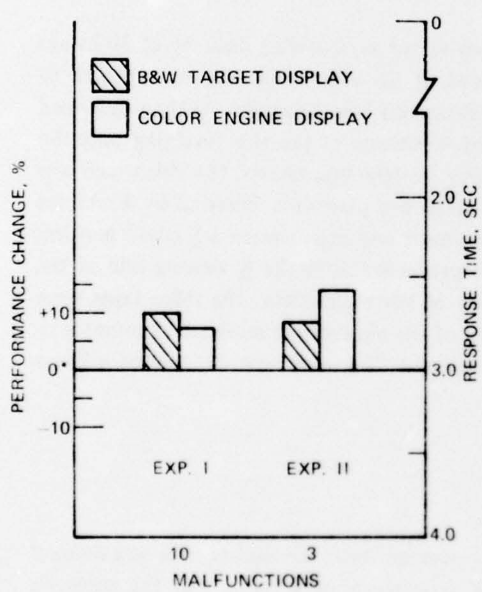

FIGURE 4. Percent Performance Change and Response Time for Experiments I and II.

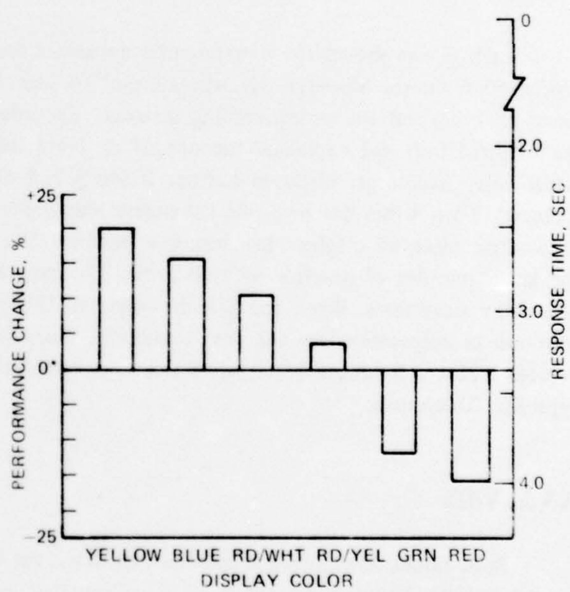

FIGURE 5. Percent Performance Change With Color Relative to B&W Displays for Experiment III (Averaged Across Three Displays).

*The performance baseline in this figure (0%) is the mean response time found for the experiment when all displays were shown in B&W.

DISPLAY COLORS

The analysis showed that display color had a significant effect on performance for all experiments. For Experiments I and II (one engine display and one scenery display) there was no difference in performance on the engine display whether it was color-coded or B&W. However, when it was color-coded, target detection time on the scenery display decreased significantly ($p < 0.01$ and $p < 0.025$, respectively, for Experiments I and II). No significant difference in response time was found between the 10 malfunctions presented in Experiment I and the 3 malfunctions presented in Experiment II.

The findings for the first and second experiments suggest that subjects were more attentive to the scenery display when the engine display was color-coded than when it was not. Additionally, the extremely low error rate (< 2% missed targets) suggests that Ss had little difficulty with the task in either color or B&W.

The analysis of Experiment III (one scenery display and two engine displays) showed that the display color affected performance on both the target display and the color engine display ($p < 0.001$), but not on the second B&W engine display. Figure 6 shows how each of the display colors compared to B&W TV in terms of percent performance change relative to response time. The mean response time (3.33 sec) when all three displays were shown in B&W TV provides the performance baseline (0%).

It can be seen that monochromatic yellow, blue, and color-coded red-on-white provided an overall higher performance level than did B&W TV. On the other hand, monochromatic red and green degraded performance while color-coded red-on-yellow was comparable to performance with B&W TV.

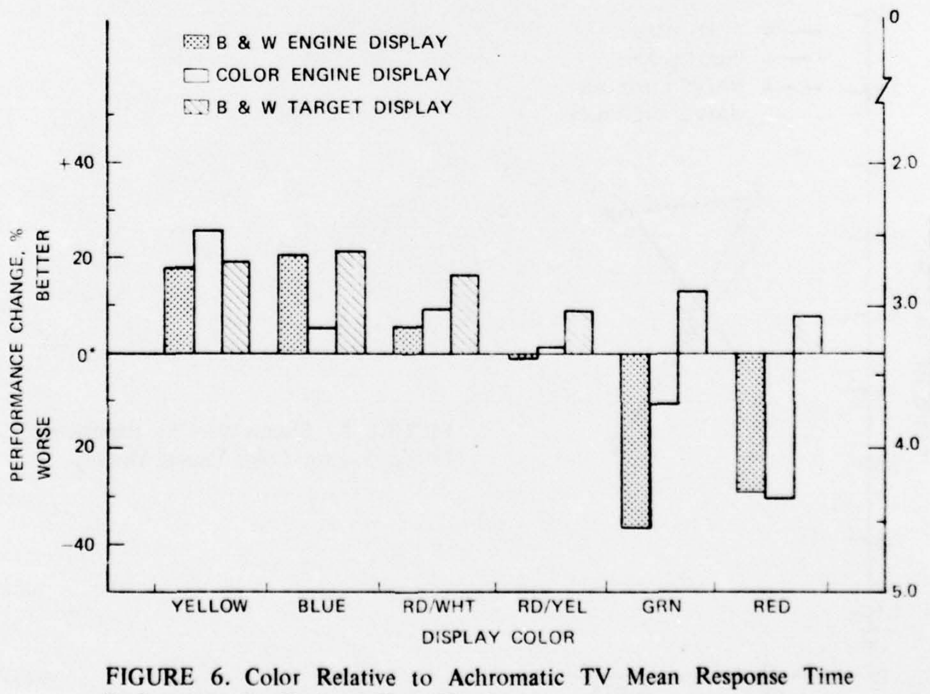

FIGURE 6. Color Relative to Achromatic TV Mean Response Time Performance for Each of Three Displays.

*The performance baseline in this figure (0%) is the mean response time found for the experiment when all displays were shown in B&W.

These experiments have shown (1) that a color-coded TV engine display, compared to a B&W TV engine display, offers some improvement in overall response time performance, and (2) that monochromatic colors on TV differentially affect performance. The rather weak performance improvement provided by color-coding may be due to the apparent easiness of the task. Error (omission) rates continued at less than 2% even when the third display was added for the final experiment. This suggests that ample time was available for subjects to accomplish the task and that their information-handling capacity was not taxed. There is some evidence to support the view that color-coding becomes more effective with increasing work loads.[23] Although it was believed the addition of a second engine display for Experiment III would test this view, clearly it did not. Also, there is the view suggesting that, with extensive practice, the initial benefits of one coding method over another, including color-coding, tend to become minimal.[3] Research is needed to simultaneously test both views.

DISPLAY ILLUMINATION

The displays for the third experiment were illuminated with low levels (4.3 lux) of either red or white light. The color of the ambient illumination did not have a significant main effect on performance. However, illumination interacted with experience to affect performance on the color engine display ($p < 0.005$). Figure 7 depicts this significant interaction. It shows that both naive subject groups performed better under white light, pilots-B/Ns performed better under red light, and the lighting made little difference to the Test-Wise group. Since performance was relatively poor for the monochromatic red condition, scores for this display color were checked against both red and white illumination. There was no difference. The performance of subjects using the red display was relatively poor under both red and white illumination.

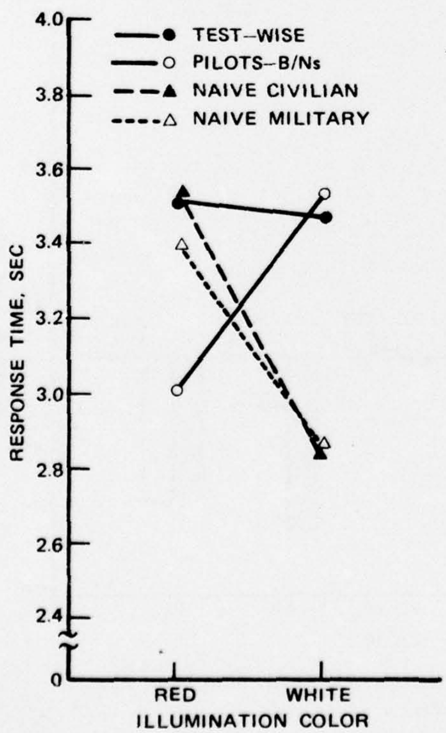

FIGURE 7. Illumination by Experience Interaction for Color Engine Display.

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[23] Honeywell, Inc. "Color Coding Research," by Majorie J. Krebs. Minneapolis, Minn., 1976. (Unpublished paper.)

Within the limits investigated, the experiment indicates that illumination color does not inherently affect the performance of detection or monitoring tasks on television. However, the illumination by experience interaction suggests that, with color displays, people used to working under one light color need some amount of additional practice to work as effectively under the other light color.

OBSERVER EXPERIENCE

Civilian subjects experienced in target acquisition tasks were compared with civilian subjects inexperienced with target acquisition tasks in the first experiment. No significant differences in performance were found between the two groups. Experience level was again investigated in the third experiment. Here, experience was split into two groups: (1) civilian (Test-Wise) and (2) military (pilots-B/Ns). Inexperience was also split into two groups: (1) civilian (naive) and (2) military (naive). No difference in malfunction detection performance on the engine displays was found between the four groups. However, experience was found to affect target-detection performance ($p < 0.001$). Application of the Newman-Keuls test to the experience factor shows that the performance of the naive military group was significantly different from the performance of the other three groups.

Inspection of the data indicates that, when the naive military group saw the targets, they had response times similar to the other three groups, but they missed three times as many targets. This suggests that, with additional practice on a target-detection task, this group would perform on a level comparable to the other three groups.

SUMMARY

The results from these three experiments investigating color-coding on television displays are summarized as follows:

1. Target detection response time on the scenery display was faster when the engine display was color-coded than when it was not.

2. Color-coding on one engine display did not affect performance on an adjacent B&W engine display of identical format.

3. Response time performance with yellow or blue monochrome engine displays was not significantly different than with color-coded displays, while performance with red or green monochrome displays was significantly slower than with color-coded displays.

4. Performance with the various display colors was not affected by the color (red or white) of the ambient illumination.

5. Experience level was not an important factor for these experiments.

6. Too few errors were made on both color and B&W displays (<2%) to adequately test the percent correct performance measure.

7. The statistically significant improvement in response time performance with some color displays is not necessarily significant in an operational sense. Additional studies employing a wider range of workloads and training are recommended and required to validate this point.

Appendix A
SUBJECTS' RECORDED INSTRUCTIONS

The purpose of this experiment is to help us determine how well people perform two tasks under varying conditions. Your primary task is to detect vehicular targets—a pair of tanks or trucks—like these on the upper TV. (E shows tandem arrangement of target-pair). When you see targets, push this button (E provides hand-held response button). If the targets appear in Sector One, push the button once; if they appear in Sector Two, push it twice, and if in Sector Three, push it three times.

Your secondary task is to monitor these indicators on the bottom two TV screens. Whenever one of these pointers exceeds the tolerance limits shown by these markers, in either direction, push the left or right button corresponding with the left or right TV, and then push the button corresponding with the out-of-tolerance indicator. If, at any time, you make an error, simply call out, "ERROR", then make the correct response and continue with the task.

Now there will be several minutes of practice. First, you will see about 4 minutes of scenery with the targets on the upper monitor.

For this part of the practice, you will hear a tone indicating that a target is present. Practice your response. Ignore the lower TVs for the moment. Ready? (E runs for 4 minutes of scenery video tape, checking the subject's responses). Now you will see 4 minutes of tape containing malfunction indications on the lower monitors. Again, practice your responses. Ignore the top monitor for the moment. Ready? (E runs 4 minutes of video tape containing malfunction indications and checks the subject's responses).

During the last part of the practice, all three TVs will be operating. For the first portion, a short beep will sound when a target is in the middle of the screen. There will be no tones the last 2 minutes of practice. Remember to watch all three screens, and make the proper responses. Ready? (E plays the next 4 minutes of the video tapes, observing the subject's responses. If any errors are made during the last 2 minutes of practice, the tapes are rerun until no errors occur during the final 2 minutes.)

There will be no more tones. This portion of the experiment will last about 22 minutes. There will be a short break, and then we'll complete the last 22 minutes. We are ready to begin. Are there any questions?

Appendix B

ERRORS

Three types of errors were committed during these experiments: (1) momentary (M)–S realized his mistake and self-corrected; (2) commission (C)–S reported targets that were not, in fact, real targets, or responded incorrectly; and (3) omission (O)–S did not respond to targets that were, in fact, present. The errors are noted by each experiment below. No further attempt was made to analyze the errors due to the paucity of data.

Experiment	Error	Experimental conditions			
		Color-coded		B&W	
I	(C) False targets	1		1	
	(O) Missed targets	2		4	
II	(C) False targets	2		0	
	(O) Missed targets	1		1	
		Experienced		Naive	
		Test-Wise	Pilots-B/Ns	Civilians	Military
III	(C) False targets	0	3	4	27
	(O) Missed targets	4	6	5	17
	(O) Missed malfunction	3	1	1	5
	(C) Pushed wrong button	0	0	1	6
	(M) Pushed wrong button	4	6	4	9

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